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Intrusion Detection System to Demonstrate Malicious Attackers in Wireless Sensor Networks

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Abstract-Mobile Ad hoc Network (MANET) is one of the most important and unique applications among all the contemporary wireless networks. Also MANET does not require a fixed network infrastructure; every single node works as both a transmitter and a receiver. Nodes communicate directly with each other when they are both within the same communication range. The advantage of MANET's is its self-configuring ability of nodes which made it popular among critical mission applications like military use or emergency recovery. MANET are vulnerable to malicious attackers. In this case, it is crucial to develop efficient intrusion-detection mechanisms to protect MANET from attacks. With the growth & wide popularity of MANET it is very vital to address its potential security iss ues. Hence the proposed project uses and implement a new intrusion-detection system named Enhanced Group signature Intrusion Detection (EGIDS) designed for MANETs. The proposed approach EAACK demonstrates higher malicious-behavior-detection rates without affecting the network performances. In this project we use the RSA algorithm to encrypt the data & AES algorithm to decrypt the same data, which are the most widely used algorithms for encryption & decryption. This algorithm is also useful in generating signatures used for security purposes.

Index Terms—Digital signature, digital signature algorithm (DSA), Enhanced Adaptive ACKnowledgment (AACK) (EAACK), Mobile Ad hoc NETwork (MANET).

I. INTRODUCTION

DUE TO THEIR natural mobility and scalability, wireless networks are always preferred since the first day of their invention. Owing to the improved technology and reduced costs, wireless networks have gained much more preferences over wired networks in the past few decades.

By definition, Mobile Ad hoc NETwork (MANET) is a collection of mobile nodes equipped with both a wireless transmitter and a receiver that communicate with each other via bidirectional wireless links either directly or indirectly. Industrial remote access and control via wireless networks are becoming more and more popular these days [35]. One of the major advantages of wireless networks is its ability to allow data communication between different parties and still maintain their mobility. However, this communication is limited to the range of transmitters. This means that two nodes cannot communicate with each other when the distance between the two nodes is beyond the communication range of their own. MANET solves this problem by allowing intermediate parties to relay data transmissions. This is achieved by dividing MANET into two types of networks, namely, single-hop and multihop. In a single-hop network, all nodes within the same radio range communicate directly with each other. On the other hand, in a multihop network, nodes rely on other intermediate nodes to transmit if the destination node is out of their radio range. In contrary to the traditional wireless network, MANET has a decentralized network infrastructure. MANET does not require a fixed infrastructure; thus, all nodes are free to move randomly [10], [27], [29]. MANET is capable of creating a self-configuring and self-maintaining network without the help of a centralized infrastructure, which is often infeasible in critical mission applications like military conflict or emergency recovery. Minimal configuration and quick deployment make MANET ready to be used in emergency circumstances where an infrastructure is unavailable or unfeasible to install in scenarios like natural or human-induced disasters, military conflicts, and medical emergency situations [19], [30].

Owing to these unique characteristics, MANET is becoming more and more widely implemented in the industry [14], [28]. However, considering the fact that MANET is popular among critical mission applications, network security is of vital importance. Unfortunately, the open medium and remote distribution of MANET make it vulnerable to various types of attacks. For example, due to the nodes' lack of physical protection, malicious attackers can easily capture and compromise nodes to achieve attacks. In particular, considering the fact that most routing protocols in MANETs assume that every node in the network behaves cooperatively with other nodes and presumably not malicious [5], attackers can easily compromise MANETs by inserting malicious or non cooperative nodes into the network. Furthermore, because of MANET's distributed architecture and changing topology, a traditional centralized monitoring technique is no longer feasible in MANETs. In such case, it is crucial to develop an intrusion-detection system (IDS) specially designed for MANETs. Many research efforts have been devoted to such research topic [1]–[3], [6]–[9], [15], [16], [22], [24], [26], [29]–[31].

In the next section, we mainly concentrate on discussing the background information required for understanding this research topic.

II. BACKGROUND

A. IDS in MANETs

As discussed before, due to the limitations of most MANET routing protocols, nodes in MANETs assume that other nodes always cooperate with each other to relay data. This assumption leaves the attackers with the opportunities to achieve significant impact on the network with just one or two compromised nodes. To address this problem, an IDS should be added to enhance the security level of MANETs. If MANET can detect the attackers as soon as they enter the network, we will be able to completely eliminate the potential damages caused by compromised nodes at the first time. IDSs usually act as the second layer in MANETs, and they are a great complement to existing proactive approaches [27]. Anantvalee and Wu [4] presented a very thorough survey on contemporary IDSs in MANETs. In this section, we mainly describe three existing approaches, namely, Watchdog [17], TWOACK [15], and Adaptive ACKnowledgment (AACK) [25].

1) Watchdog: Marti *et al.* [17] proposed a scheme named Watchdog that aims to improve the throughput of network with the presence of malicious nodes. In fact, the Watchdog scheme is consisted of two parts, namely, Watchdog and Pathrater. Watchdog serves as an IDS for MANETs. It is responsible for detecting malicious node misbehaviors in the network. Watchdog detects malicious misbehaviors by promiscuously listening to its next hop's transmission. If a Watchdog node overhears that its next node fails to forward the packet within a certain period of time, it increases its failure counter. Whenever a node's failure counter exceeds a predefined threshold, the Watchdog node reports it as misbehaving. In this case, the Pathrater cooperates with the routing protocols to avoid the reported nodes in future transmission.

Many following research studies and implementations have proved that the Watchdog scheme is efficient. Furthermore, compared to some other schemes, Watchdog is capable of detecting malicious nodes rather than links. These advantages have made the Watchdog scheme a popular choice in the field. Many MANET IDSs are either based on or developed as an improvement to the Watchdog scheme [15], [20], [21], [25]. Nevertheless, as pointed out by Marti *et al.* [17], the Watchdog scheme fails to detect malicious misbehaviors with the presence of the following: 1) ambiguous collisions; 2) receiver collisions; 3) limited transmission power; 4) false misbehavior report; 5) collusion; and 6) partial dropping. We discuss these weaknesses with further detail in Section III.

2) TWOACK: With respect to the six weaknesses of the Watchdog scheme, many researchers proposed new approaches to solve these issues. TWOACK proposed by Liu *et al.* [16] is one of the most important approaches among them. On

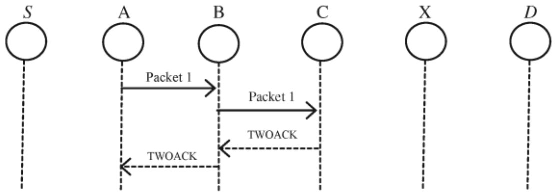

Fig. 1. TWOACK scheme: Each node is required to send back an acknowledgment packet to the node that is two hops away from it.

the contrary to many other schemes, TWOACK is neither an enhancement nor a Watchdog-based scheme. Aiming to resolve the receiver collision and limited transmission power problems of Watchdog, TWOACK detects misbehaving links by acknowledging every data packet transmitted over every three consecutive nodes along the path from the source to the destination. Upon retrieval of a packet, each node along the route is required to send back an acknowledgment packet to the node that is two hops away from it down the route. TWOACK is required to work on routing protocols such as Dynamic Source Routing (DSR) [11]. The working process of TWOACK is shown in Fig. 1: Node A first forwards Packet 1 to node B, and then, node B forwards Packet 1 to node C. When node C receives Packet 1, as it is two hops away from node A, node C is obliged to generate a TWOACK packet, which contains reverse route from node A to node C, and sends it back to node A. The retrieval of this TWOACK packet at node A indicates that the transmission of Packet 1 from node A to node C is successful. Otherwise, if this TWOACK packet is not received in a predefined time period, both nodes B and C are reported malicious. The same process applies to every three consecutive nodes along the rest of the route.

The TWOACK scheme successfully solves the receiver collision and limited transmission power problems posed by Watchdog. However, the acknowledgment process required in every packet transmission process added a significant amount of unwanted network overhead. Due to the limited battery power nature of MANETs, such redundant transmission process can easily degrade the life span of the entire network. However, many research studies are working in energy harvesting to deal with this problem [25], [28], [29].

3) AACK: Based on TWOACK, Sheltami *et al.* [25] proposed a new scheme called AACK. Similar to TWOACK, AACK is an acknowledgment-based network layer scheme which can be considered as a combination of a scheme called TACK (identical to TWOACK) and an end-to-end acknowledgment scheme called ACKnowledge (ACK). Compared to TWOACK, AACK significantly reduced network overhead while still capable of maintaining or even surpassing the same network throughput. The end-to-end acknowledgment scheme in ACK is shown in Fig. 2.

In the ACK scheme shown in Fig. 2, the source node S sends out Packet 1 without any overhead except 2 b of flag indicating the packet type. All the intermediate nodes simply forward this packet. When the destination node D receives Packet 1, it is required to send back an ACK acknowledgment packet to the source node S along the reverse order of the

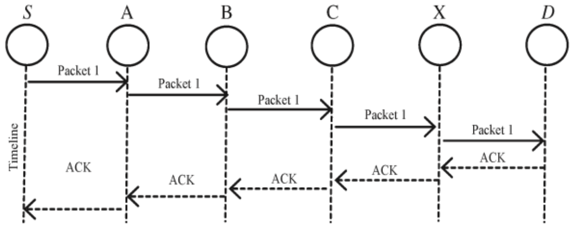

Fig. 2. ACK scheme: The destination node is required to send acknowledgment packets to the source node.

same route. Within a predefined time period, if the source node S receives this ACK acknowledgment packet, then the packet transmission from node S to node D is successful. Otherwise, the source node S will switch to TACK scheme by sending out a TACK packet. The concept of adopting a hybrid scheme in AACK greatly reduces the network overhead, but both TWOACK and AACK still suffer from the problem that they fail to detect malicious nodes with the presence of false misbehavior report and forged acknowledgment packets.

In fact, many of the existing IDSs in MANETs adopt an acknowledgment-based scheme, including TWOACK and AACK. The functions of such detection schemes all largely depend on the acknowledgment packets. Hence, it is crucial to guarantee that the acknowledgment packets are valid and authentic. To address this concern, we adopt a digital signature in our proposed scheme named Enhanced AACK (EAACK).

B. Digital Signature

Digital signatures have always been an integral part of cryptography in history. Cryptography is the study of mathematical techniques related to aspects of information security such as confidentiality, data integrity, entity authentication, and data origin authentication [18]. The development of cryptography technique has a long and fascinating history. The pursuit of secure communication has been conducted by human being since 4000 years ago in Egypt, according to Kahn’s book [30] in 1963. Such development dramatically accelerated since the World War II, which some believe is largely due to the globalization process.

The security in MANETs is defined as a combination of processes, procedures, and systems used to ensure confidentiality, authentication, integrity, availability, and nonrepudiation [18]. Digital signature is a widely adopted approach to ensure the authentication, integrity, and nonrepudiation of MANETs. It can be generalized as a data string, which associates a message (in digital form) with some originating entity, or an electronic analog of a written signature [33].

Digital signature schemes can be mainly divided into the following two categories.

1) *Digital signature with appendix*: The original message is required in the signature verification algorithm. Examples include a digital signature algorithm (DSA) [33].
2) *Digital signature with message recovery*: This type of scheme does not require any other information besides the signature itself in the verification process. Examples include RSA [23].

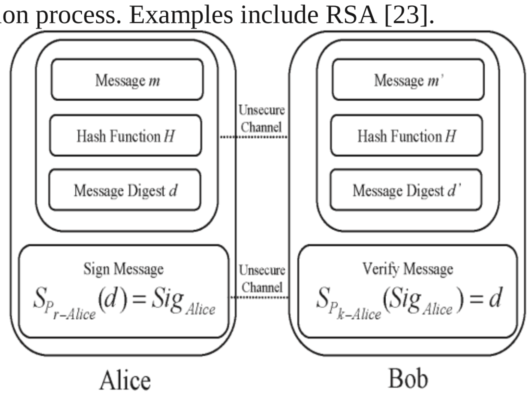

Fig. 3. Communication with digital signature.

In this research work, we implemented both DSA and RSA in our proposed EAACK scheme. The main purpose of this implementation is to compare their performances in MANETs.

The general flow of data communication with digital signature is shown in Fig. 3. First, a fixed-length message digest is computed through a preagreed hash function *H* for every message *m*. This process can be described as

$$H(m) = d. \quad (1)$$

Second, the sender Alice needs to apply its own private key $P_r{-}Alice$ on the computed message digest *d*. The result is a signature Sig_{Alice}, which is attached to message *m* and Alice’s secret private key

$$S_{Pr-}Alice(d) = Sig_{\text{Alice}}. \quad (2)$$

To ensure the validity of the digital signature, the sender Alice is obliged to always keep her private key $P_r{-}Alice$ as a secret without revealing to anyone else. Otherwise, if the attacker Eve gets this secret private key, she can intercept the message and easily forge malicious messages with Alice’s signature and send them to Bob. As these malicious messages are digitally signed by Alice, Bob sees them as legit and authentic messages from Alice. Thus, Eve can readily achieve malicious attacks to Bob or even the entire network.

Next, Alice can send a message *m* along with the signature Sig_{Alice} to Bob via an unsecured channel. Bob then computes the received message *m* against the preagreed hash function H to get the message digest *d*. This process can be generalized as

$$H(m') = d'. \quad (3)$$

Bob can verify the signature by applying Alice's public key $P_{k\text{–}}Alice$ on Sig_{Alice}, by using

$$S_{Pk\text{–}}Alice(Sig_{\text{Alice}}) = d. \quad (4)$$

If $d == d'$, then it is safe to claim that the message *m* transmitted through an unsecured channel is indeed sent from Alice and the message itself is intact.

III. PROBLEM DEFINITION

Our proposed approach EAACK is designed to tackle three of the six weaknesses of Watchdog scheme, namely, false misbehavior, limited transmission power, and receiver collision. In this section, we discuss these three weaknesses in detail.

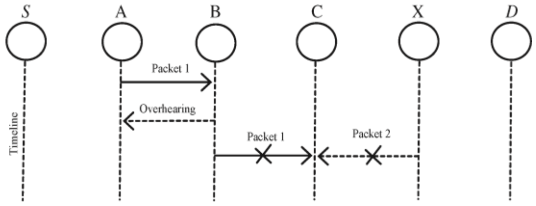

Fig. 4. Receiver collisions: Both nodes B and X are trying to send Packet 1 and Packet 2, respectively, to node C at the same time.

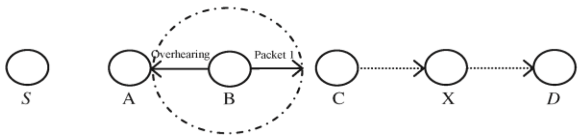

Fig. 5. Limited transmission power: Node B limits its transmission power so that the packet transmission can be overheard by node A but too weak to reach node C.

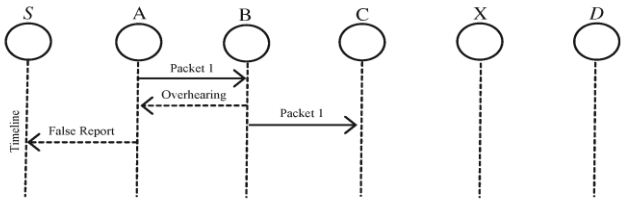

Fig. 6. False misbehavior report: Node A sends back a misbehavior report even though node B forwarded the packet to node C.

In a typical example of receiver collisions, shown in Fig. 4, after node A sends Packet 1 to node B, it tries to overhear if node B forwarded this packet to node C; meanwhile, node X is forwarding Packet 2 to node C. In such case, node A overhears that node B has successfully forwarded Packet 1 to node C but failed to detect that node C did not receive this packet due to a collision between Packet 1 and Packet 2 at node C.

In the case of limited transmission power, in order to preserve its own battery resources, node B intentionally limits its transmission power so that it is strong enough to be overheard by node A but not strong enough to be received by node C, as shown in Fig. 5.

For false misbehavior report, although node A successfully overheard that node B forwarded Packet 1 to node C, node A still reported node B as misbehaving, as shown in Fig. 6. Due to the open medium and remote distribution of typical MANETs, attackers can easily capture and compromise one or two nodes to achieve this false misbehavior report attack.

As discussed in previous sections, TWOACK and AACK solve two of these three weaknesses, namely, receiver collision and limited transmission power. However, both of them are vulnerable to the false misbehavior attack. In this research work, our goal is to propose a new IDS specially designed for MANETs, which solves not only receiver collision and limited transmission power but also the false misbehavior problem.

Furthermore, we extend our research to adopt a digital signature scheme during the packet transmission process. As in all acknowledgment-based IDSs, it is vital to ensure the integrity and authenticity of all acknowledgment packets.

Table I: Packet Type Indicators

Packet Type	Packet Flag
General Data	00
ACK	01
S-ACK	10
MRA	11

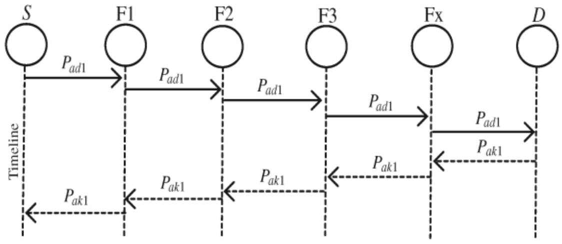

Fig. 7. System control flow: This figure shows the system flow of how the EAACK scheme works.

IV. WORKING PRINCIPLE

EGIDS is consisted of three major parts, namely, ACK, secure ACK (S-ACK), and misbehavior report authentication (MRA). In order to distinguish different packet types in different schemes, we included a 2-b packet header in EGIDS. According to the Internet draft of DSR, there is 6 b reserved in the DSR header. In EGIDS, we use 2 b of the 6 b to flag different types of packets.

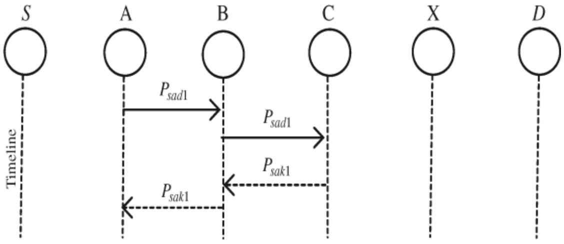

Fig. 8. ACK scheme: The destination node is required to send back an acknowledgment packet to the source node when it receives a new packet.

Please note that, in our proposed scheme, we assume that the link between each node in the network is bidirectional. Furthermore, for each communication process, both the source node and the destination node are not malicious. Unless specified, all acknowledgment packets described in this research are required to be digitally signed by its sender and verified by its receiver.

A. ACK

As discussed before, ACK is basically an end-to-end acknowledgment scheme. It acts as a part of the hybrid scheme in EGIDS, aiming to reduce network overhead when no network misbehavior is detected. In Fig. 8, in ACK mode, node S first sends out an ACK data packet *Pad*1 to the destination node D. If all the intermediate nodes along the route between nodes S and D are cooperative and node D successfully receives *Pad*1, node D is required to send back an ACK acknowledgment packet *Pak*1 along the same route but in a reverse order. Within a predefined time period, if node S receives *Pak*1, then the packet transmission from node S to node D is successful. Otherwise, node S will switch to S-ACK mode by sending out an S-ACK data packet to detect the misbehaving nodes in the route.

B. S-ACK

The S-ACK scheme is an improved version of the TWOACK scheme proposed by Liu. The principle is to let every three consecutive nodes work in a group to detect misbehaving nodes. For every three consecutive nodes in the route, the third node is required to send an S-ACK acknowledgment packet to the first node. The intention of introducing S-ACK mode is to detect misbehaving nodes in the presence of receiver collision or limited transmission power.

As shown in Fig. 8, in S-ACK mode, the three consecutive nodes (i.e., F1, F2, and F3) work in a group to detect misbehaving nodes in the network. Node F1 first sends out S-ACK data packet *Psad*1 to node F2. Then, node F2 forwards this packet to node F3. When node F3 receives *Psad*1, as it is the third node in this three-node group, node F3 is required to send back an S-ACK acknowledgment packet *Psak*1 to node F2. Node F2 forwards *Psak*1 back to node F1. If node F1 does not receive this acknowledgment packet within a predefined time period, both nodes F2 and F3 are reported as malicious. Moreover, a misbehavior report will be generated by node F1 and sent to the source node S.

Nevertheless, unlike the TWOACK scheme, where the source node immediately trusts the misbehavior report, EGIDS requires the source node to switch to MRA mode and confirm this misbehavior report. This is a vital step to detect false misbehavior report in our proposed scheme.

C. MRA

The MRA scheme is designed to resolve the weakness of Watchdog when it fails to detect misbehaving nodes with the presence of false misbehavior report. The false misbehavior report can be generated by malicious attackers to falsely report innocent nodes as malicious. This attack can be lethal to the entire network when the attackers break down sufficient nodes and thus cause a network division. The core of MRA scheme is to authenticate whether the destination node has received the reported missing packet through a different route.

To initiate the MRA mode, the source node first searches its local knowledge base and seeks for an alternative route to the destination node. If there is no other that exists, the source node starts a DSR routing request to find another route. Due to the nature of MANETs, it is common to find out multiple routes between two nodes.

By adopting an alternative route to the destination node, we circumvent the misbehavior reporter node. When the destination node receives an MRA packet, it searches its local knowledge knowledge base and compares if the reported packet was received. If it is already received, then it is safe to conclude that this is a false misbehavior report and whoever generated this report is marked as malicious. Otherwise, the misbehavior report is trusted and accepted.

By the adoption of MRA scheme, EGIDS is capable of detecting malicious nodes despite the existence of false misbehavior report.

D. DIGITAL SIGNATURE

As discussed before, EGIDS is an acknowledgment-based IDS. All three parts of EGIDS, namely, ACK, S-ACK, and MRA, are acknowledgment-based detection schemes. They all rely on acknowledgment packets to detect misbehaviors in the network. Thus, it is extremely important to ensure that all acknowledgment packets in EGIDS are authentic and untainted. Otherwise, if the attackers are smart enough to forge acknowledgment packets, all of the three schemes will be vulnerable. With regard to this urgent concern, we incorporated digital signature in our proposed scheme. In order to ensure the integrity of the IDS, EGIDS requires all acknowledgment packets to be digitally signed before they are sent out and verified until they are accepted. However, we fully understand the extra resources that are required with the introduction of digital signature in MANETs. To address this concern, we implemented both DSA and RSA digital signature schemes in our proposed approach. The goal is to find the most optimal solution for using digital signature in MANETs.

V. CONCLUSION

Packet-dropping attack has always been a major threat to the security in MANETs. In this project, we have proposed a novel IDS named EGIDS protocol specially designed for MANETs and compared it against other popular mechanisms in different scenarios through simulations. The results demonstrated positive performances against Watchdog, TWOACK, and AACK in the cases of receiver collision, limited transmission power, and false misbehavior report. Furthermore, in an effort to prevent the attackers from initiating forged acknowledgment attacks, we extend our research to incorporate digital signature in our proposed scheme. Although it generates more ROs in some cases, as demonstrated in our experiment, it can vastly improve the network's PDR when the attackers are smart enough to forge acknowledgment packets. We think that this tradeoff is worthwhile when network security is the top priority. In order to seek the optimal DSAs in MANETs, we implemented both DSA and RSA schemes in our simulation. Eventually, we arrived to the conclusion that the DSA scheme is more suitable to be implemented in MANETs.

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